Land surface modeling in Arid and Semi-arid regions

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Chinese Academy of Sciences

The 2nd Summer School on Land Surface Observing, Modeling and Data Assimilation
13-16 July 2010, Beijing Normal University, Beijing, China
My winter school

♦ land surface processes: concept
♦ The role of land surface in climate system and its modeling
♦ Lecture 3 Solution of similarity theory
♦ Lecture 4 Flux parameterization
♦ Lecture 5 canopy model
♦ Lecture 6 parameter measurement and soil heat flux
♦ Lecture 7 part 1 soil water flow
♦ Lecture 8 part 2 soil freezing and thawing
♦ Lecture 9 Land surface model SiB2
Outline

♦ Philosophy of process studies

♦ Data analysis for heat transfer resistance over bare soil surface

♦ Heat transfer resistance was under-estimated in models: results from CEOP model inter-comparison

♦ Can models be improved after implement a realistic flux parameterization scheme?

♦ Field work and lab. Experiments contribute to new knowledge
Strategy to improve a model’s processes

♦ It is easy to identify model biases/uncertainties

♦ It is crucial to identify
  – Parameter issue or parameterization issue
  – which process is misrepresented in the model

♦ It is target to establish an appropriate representation scheme and implement into the model.
Parameter or parameterization

Correct parameters

Small biases

Correct Parameterization

Big biases

Wrong parameters

Small biases

Wrong Parameterization
Philosophy

- Calibrations contribute to better model performance but prevent us from understanding processes in a model;
- We should specify model parameter values as accurate as possible, though it is difficult to provide all;
- Processes Parameterization investigation should be based on appropriate specification of model parameters;
- Though a process may become dominant in a climate regime, we should pursue a universally applicable parameterization;
- Try to separate processes from a complex system; simple and extreme conditions help identify misrepresented processes
How to identify which process is misrepresented in complex process interactions
Three examples show how to separate processes?

♦ Observations over simple surfaces: Desert observations for thermal processes study

♦ Glacier observations for very stable boundary flux parameterization

♦ Extreme conditions to amplify model biases:
  – Tibetan observations
2009/06/20-2009/06/25

Variation of Turbulent flux at Xiaotang Station
Diurnal variations of air temperature

Winter

Average Air Temp/°C

Hour

Summer

Average Air Temp/°C

Hour
Diurnal variations of soil temperature

Winter

Summer
Merits of Xiaotang station

- Thermal processes dominate → Easy to separate thermal processes from water exchange processes → Improve models
- Suitable to test free convective processes and very stable boundary scheme
- Suitable to test evaporation and infiltration scheme after rainfall over dry soils?
Observations on a Glacier

♦ In the ‘field’

*Eddy-covariance system, Radiation, Met. quantity, Ice temp, Mass balance*
Favorable for studies on
1. Condensation, sublimation
2. Very stable boundary layer
11 comprehensive observation stations are now been implementing by Chinese Academy of Sciences (CAS)
GAME-Tibet and CAMP-Tibet Observation network
Wind Profiler and RASS

40m PBL tower

Turbulent system, CO$_2$/H$_2$O flux and radiation system

Wind Profiler and RASS

GPS
Merits of Tibetan stations

♦ Strong seasonal and diurnal variations in all energy components and soil temperature
♦ Soil freezing and thawing processes
♦ Suitable to test how soil organic matters affect soil parameters
Central Tibetan Plateau: land cover
In rainy season:
short grasses, dense roots

In dry season:
no grasses, dense roots

In Eastern Tibet:
Topsoil = dense roots + soil
Deepsoil = little roots + soil
High soil water contents are observed in top soils, where high soil organic matters are found.
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Energy partition

Dense canopy

Sparse canopy

Bare soil

$H_c \gg H_g$

$H_c \sim H_g$

$H = H_g$
Concept of heat transfer

\[ H = \rho c_p \frac{T_{sfc} - T_{air}}{r_h} \]

- **Aerodynamic roughness length**
  - \( z_{0m} \)
  - \( r_h = Pr[\ln \frac{z_m}{z_{0m}} - \psi_m] [\ln \frac{z_h}{z_{0h}} - \psi_h] / [k^2 U] \)
  - ~Surface roughness dependent

- **Thermal roughness length???

- **Resistance**
  - \( kB^{-1} = \ln \frac{z_{0m}}{z_{0h}} \)
**Parameterization schemes for $kB^{-1}$**

<table>
<thead>
<tr>
<th>Formula</th>
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</tr>
</thead>
<tbody>
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<td>Kanda et al. (2007)</td>
<td>K07</td>
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<tr>
<td>$z_{0h} = \frac{70 \nu}{\mu_\ast} \exp(-\beta u_\ast^{0.5}</td>
<td>T_\ast</td>
<td>^{0.25})$</td>
</tr>
</tbody>
</table>

Which shows the physics? Which is better?
Recent Field experiments in East Asia (HEIFE, GAME, CEOP, BNU)

1. Grassland
2. Earth hummock
3. Grassland
4. Gobi
5. Desert
6. Cropland
7. Grassland
8. Cropland

Plateau
Arid
Semi-arid
## Instruments List

<table>
<thead>
<tr>
<th>No.</th>
<th>Instrument</th>
<th>Model</th>
<th>Company</th>
<th>Mount high or depth</th>
<th>Data interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Anemometer</td>
<td>CSAT3</td>
<td>Campbell,USA</td>
<td>3m</td>
<td>10Hz</td>
</tr>
<tr>
<td>2</td>
<td>CO2/H2O Analyzer</td>
<td>LICOR7500</td>
<td>Licor,USA</td>
<td>3m</td>
<td>10Hz</td>
</tr>
<tr>
<td>3</td>
<td>Air Temperature and RH Probe</td>
<td>HMP45C</td>
<td>VAISALA, Finland</td>
<td>3m</td>
<td>10Hz</td>
</tr>
<tr>
<td>4</td>
<td>Net Radiometer</td>
<td>CNR-1</td>
<td>Kipp&amp;Zonen, Netherland</td>
<td>1.5m</td>
<td>1s</td>
</tr>
<tr>
<td>5</td>
<td>Infrared Radiometer</td>
<td>IRR-P</td>
<td>Apogee, USA</td>
<td>1.5m</td>
<td>1s</td>
</tr>
<tr>
<td>6</td>
<td>Soil Temperature Probe</td>
<td>109L</td>
<td>Campbell, USA</td>
<td>0cm, 5cm, 10cm, 20cm, 40cm</td>
<td>10s</td>
</tr>
<tr>
<td>7</td>
<td>Heat Flux Plate</td>
<td>HFP01</td>
<td>Hukseflux, USA</td>
<td>2.5cm, 5cm</td>
<td>10s</td>
</tr>
<tr>
<td>8</td>
<td>Water Content Reflectometer</td>
<td>CS616</td>
<td>Campbell, USA</td>
<td>2.5cm, 5cm, 10cm, 20cm</td>
<td>10s</td>
</tr>
<tr>
<td>9</td>
<td>Averaging Soil Thermocouple Probe</td>
<td>TCAV</td>
<td>Campbell, USA</td>
<td>2cm, 6cm</td>
<td>10s</td>
</tr>
<tr>
<td>10</td>
<td>Data logger</td>
<td>CR3000, CR1000</td>
<td>Campbell, USA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Garmin GPS Receiver</td>
<td>GPS16-HVS</td>
<td>Garmin, Taiwan</td>
<td>1.5m</td>
<td>24h</td>
</tr>
</tbody>
</table>
Parameter determination

♦ Data quality control

♦ $Z_{0m}$ (aerodynamic roughness length)

♦ Surface emissivity
Quality control: reject data

$$
\min(H_{prf}, H_{obs}) < 0.5 \max(H_{prf}, H_{obs})
$$

$$
\left[ \left( \frac{u_{*obs}}{U} \right)^2 - k^2 \left/ \left( \ln \frac{z_m}{z_{0m}} - \psi_m \left( \frac{z_{0m}}{L_{obs}} , \frac{z_m}{L_{obs}} \right) \right)^2 \right. \right] \left/ \left[ k^2 \left/ \left( \ln \frac{z_m}{z_{0m}} \right)^2 \right. \right. \right] > 1
$$

$$
H_{obs} < 0.8 \min(H_{sfc}^{S58}, H_{sfc}^{OT63}, H_{sfc}^{B82}, H_{sfc}^{Z95}, H_{sfc}^{Z97}, H_{sfc}^{K07}, H_{sfc}^{Y07})
$$

$$
H_{obs} > 1.2 \max(H_{sfc}^{S58}, H_{sfc}^{OT63}, H_{sfc}^{B82}, H_{sfc}^{Z95}, H_{sfc}^{Z97}, H_{sfc}^{K07}, H_{sfc}^{Y07})
$$

$$
z_{0h} > 0.1z_h
$$

$$
|H| < 10 \text{ W m}^{-2}
$$
Estimate $z_{0m}$

Frequency distribution of $\ln(z_{0m})$, derived with observed $u^*$ and wind speed for GAME/Amdo site. The optimal value of $\ln(z_{0m})$ is $-7.1$.

(Yang et al., JAMC 2008)
\( z_{0m} \)

(Yang et al., JAMC 2008)
Estimate Surface emissivity

Not sensitive to selected scheme

(Yang et al., JAMC 2008)
Surface emissivity \((T_{sfc} = f(\text{emit}, R_{\text{down}}, R_{\text{up}}))\)

(Yang et al., JAMC 2008)
Data coverage

(1) Tibet highland / Arid / Semi-arid regions

(2) Smooth / Rough surfaces (0.5 ~ 10 mm)

(3) Long-term record

(4) Large range of Tg-Ta (up to 35 K)

(5) Large range of sensible heat flux (H_{min} < -50 ~ H_{max} > 400)
\[ kB^{-1} = \ln\left(\frac{z_{0m}}{z_{0h}}\right) \]

(Yang et al., JAMC 2008)
More cases in Tibet

Diurnal variation is the most important feature of thermal roughness length, particularly in Tibet
青藏高原观测平台（TORP）
Evaluation of $kB^{-1}$ schemes

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<td>$z_{oh} = \frac{70 \nu}{u_<em>} \exp(-\beta u_</em>^{0.5}</td>
<td>T_*</td>
<td>^{0.25})$</td>
</tr>
</tbody>
</table>
Diurnal variation

(Yang et al., JAMC 2008)
Sensible heat fluxes by Yang et al. (2007) scheme

Amdo
\[ y = 1.0119x \]
\[ R^2 = 0.9875 \]

NPAM
\[ y = 0.9319x \]
\[ R^2 = 0.9561 \]

Naqu
\[ y = 0.9963x \]
\[ R^2 = 0.8892 \]

Desert
\[ y = 0.9777x \]
\[ R^2 = 0.9357 \]

Gobi
\[ y = 0.9817x \]
\[ R^2 = 0.9809 \]

TY-grass
\[ y = 1.1523x \]
\[ R^2 = 0.9723 \]

TY-cropland
\[ y = 1.0735x \]
\[ R^2 = 0.9295 \]

TY-grass
\[ y = 1.1523x \]
\[ R^2 = 0.9723 \]

XTS
\[ y = 0.9119x \]
\[ R^2 = 0.9029 \]

TY-grass
\[ y = 1.1523x \]
\[ R^2 = 0.9723 \]

TY-cropland
\[ y = 1.0735x \]
\[ R^2 = 0.9295 \]
Sensitivity to surface emissivity: $R^2$

(Yang et al., JAMC 2008)
Yang, K. et al., 2008:
Turbulent flux transfer over bare soil surfaces: Characteristics and parameterization
*Journal of Applied Meteorology and Climatology, 40*(1), 276-290
Observation on Palong No.4 Glacier

Turbulence

Stake matrix (3*3)
Sensible heat flux parameterization

(a) Andreas (1987)

\[ H_{BA} = 0.56 \times H_{EC} - 12.0 \]  
\( (R^2 = 0.85) \)

(b) Yang et al. (2002)

\[ H_{BA} = 0.74 \times H_{EC} - 13.4 \]  
\( (R^2 = 0.91) \)

(c) Smeets and van den Broeke (2008b)

\[ H_{BA} = 0.93 \times H_{EC} - 12.4 \]  
\( (R^2 = 0.90) \)
Latent heat flux parameterization

(a) Andreas (1987)

\[ LE_{BA}^T = 0.81 \times LE_{EC}^T - 0.95 \]  
\[ (R^2 = 0.91) \]

(b) Yang et al. (2002)

\[ LE_{BA}^T = 1.00 \times LE_{EC}^T - 1.11 \]  
\[ (R^2 = 0.92) \]

(c) Smeets and van den Broeke (2008b)

\[ LE_{BA}^T = 1.18 \times LE_{EC}^T - 1.47 \]  
\[ (R^2 = 0.93) \]
## Error indices

### Sensible heat flux

<table>
<thead>
<tr>
<th>$z_{OH}$</th>
<th>MAD (W m$^{-2}$)</th>
<th>MBE (W m$^{-2}$)</th>
<th>RMSE (W m$^{-2}$)</th>
<th>MAPD (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Andreas (1987)</td>
<td>12.5</td>
<td>11.8</td>
<td>15.5</td>
<td>21</td>
</tr>
<tr>
<td>Yang et al. (2002)</td>
<td>5.2</td>
<td>0.4</td>
<td>6.9</td>
<td>11</td>
</tr>
<tr>
<td>Smeets and van den</td>
<td>9.3</td>
<td>−8.9</td>
<td>10.9</td>
<td>20</td>
</tr>
<tr>
<td>Broeke (2008b)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Latent heat flux

<table>
<thead>
<tr>
<th>$z_{OQ}$</th>
<th>MAD (W m$^{-2}$)</th>
<th>MBE (W m$^{-2}$)</th>
<th>RMSE (W m$^{-2}$)</th>
<th>MAPD (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Andreas (1987)</td>
<td>6.9</td>
<td>−3.4</td>
<td>8.9</td>
<td>52</td>
</tr>
<tr>
<td>Yang et al. (2002)</td>
<td>6.3</td>
<td>−1.0</td>
<td>7.8</td>
<td>57</td>
</tr>
<tr>
<td>Smeets and van den</td>
<td>7.9</td>
<td>0.9</td>
<td>10.1</td>
<td>65</td>
</tr>
<tr>
<td>Broeke (2008b)</td>
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♦ Philosophy of process studies

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CEOP (Coordinated Enhanced Observing Period)

Japan Meteorological Agency

National Centers for Environmental Prediction

Bureau of Meteorology Research Centre

UK Met Office

Experimental Climate Prediction Center

Global Land Data Assimilation Systems (GLDAS)
CEOP: cover a variety of climate regimes

In-situ & MOLTS data: CEOP/EOP3 (Oct. 2002-Sep. 2003)

- Japan Meteorological Agency
- National Centers for Environmental Prediction
- Australian Government Bureau of Meteorology
- UK Met Office
- Experimental Climate Prediction Center
- Global Land Data Assimilation Systems (GLDAS)
# Data

## CEOP/EOP3 (1<sup>st</sup> Oct 2002 ~ 30<sup>th</sup> September 2003)

<table>
<thead>
<tr>
<th>In-situ</th>
<th>GCMs</th>
<th>Satellite</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tair: 24; Qair: 21</td>
<td>JMA, BMRC</td>
<td>GEOS</td>
</tr>
<tr>
<td>Rainfall: 19; Tsfc:14</td>
<td>NCEP, ECPC</td>
<td>GMS</td>
</tr>
<tr>
<td>Radiation: 21; Flux: 8</td>
<td>UKMO</td>
<td></td>
</tr>
</tbody>
</table>

## Center | Model Name | Horizontal Resolution | Output Resolution |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>BMRC A/F</td>
<td>Operational Global Medium Range Prediction Model</td>
<td>80km</td>
<td>1 hr</td>
</tr>
<tr>
<td>ECPC</td>
<td>Seasonal Forecast Model</td>
<td>280km</td>
<td>3 hr</td>
</tr>
<tr>
<td>JMA</td>
<td>GSM for operational global data assimilation system</td>
<td>60km</td>
<td>3 hr</td>
</tr>
<tr>
<td>NCEP</td>
<td>Global Forecast System</td>
<td>50km</td>
<td>3 hr</td>
</tr>
<tr>
<td>UKMO A/F</td>
<td>Global Unified Model</td>
<td>85km</td>
<td>1 hr</td>
</tr>
</tbody>
</table>
Part II: Surface Energy Budget

\[ R_n = H + lE + G \]
Surface energy budget: Seasonal Variation

1. Too strong seasonal variations
2. Highest sensible heat in ECPC
3. Highest latent heat in NCEP
4. BMRC does not follow seasonal trend
Surface energy budget: Diurnal Variation

1. Unable to predict nighttime fluxes
2. Too late peak of latent heat
Deficiency in operational models

Composite of 13 sites-365 days

$T_g - T_a$: Observed > GCM

(Yang et al., JMSJ 2007)
Deficiency in operational models

(a) Tongyu

T_{surface}-T_{air} (K)

In situ  NCEP  JMA  UKMO  ECPC

Tg-Ta: Observed > GCM

(Yang et al., JMSJ 2007)
Deficiency in operational models

Composite of 13 sites-365 days

Sensible heat: Observed < GCM

(Yang et al., JMSJ 2007)
Heat transfer resistance

\[ H = \rho c_p \frac{T_{sfc} - T_{air}}{r_h} \]

\[ r_h = \rho c_p \frac{T_{sfc} - T_{air}}{H} \]

Heat transfer resistances are much under-estimated in GCMs for arid and semi-arid regions

(Yang et al., JMSJ 2007)
Yang, K. et al., 2007:

Initial CEOP-based review of prediction skill of operational general circulation models and land surface models,

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Is this parameterization important for land surface modeling?

1. Select dry sites in order to remove water budget effect
2. Well specify model parameters to separate the process from parameter errors
The climate of these three sites are mainly controlled by westerlies.
Climate Characteristics of alpine desert

Shiquanhe & Gaize

Precipitation: 25 mm at Shiquanhe and no rainfall at Gaize during simulation period;
Land surface is characterized by alpine desert;

**Observed soil moisture at SQH**

**Observed soil moisture at Gaize**
Performance of three LSMs - At alpine desert sites

Observed $T_{sfc}$ vs. Simulations by three LSMs

It is common that daytime land surface temperatures in arid and semi-arid regions are not well simulated in current LSMs (Hogue et al. 2005; Yang et al. 2007).
Key parameters

Surface Energy Balance (SEB) equation in Noah LSM

\[
R_{net} = (1 - \alpha)S_{\downarrow} + \varepsilon L_{\downarrow} - \sigma T_{sfc}^4
\]

\[R_{net} = H + LE + G_0\]

\[H = \rho c_p C_h u[T_{sfc} - \theta_{air}]\]

\[G_0 = k_T(\Theta_1) \frac{T_{sfc} - T_1}{h_1}\]

Albedo (\(\alpha\)), emissivity (\(\varepsilon\)) and soil thermal conductivity (\(k_T\)) can be derived from observations.

Surface exchange coefficient for heat (\(C_h\)) is mainly determined by the thermal roughness length (\(z_{0h}\)) and aerodynamic roughness length (\(z_{0m}\)).
Sensitivity to thermal roughness length ($z_{0h}$)

Six $z_{0h}$ schemes were implemented in Noah LSM, including:

1) S58 (Sheppard 1958)  
2) B82 (Brutsaert 1982)  
3) Z95 (Zilitinkevich 1995)  
4) Z98 (Zeng et al. 1998)  
5) K07 (Kanda et al. 2007)  
6) Y07 (Yang et al. 2007)

Y08 gives the smaller BIAS, RMSE in Tsfc than other schemes.
Implement our observation-based scheme (Y07) into SiB2

(Yang et al., HESS 2009)
Performance of revised Noah - at Shiquanhe site

Error metrics for daytime (09:00-16:00 local time)

<table>
<thead>
<tr>
<th></th>
<th>$T_{sfc}$</th>
<th>$H$</th>
<th>$R_{net}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BIAS</td>
<td>MD</td>
<td>RMSD</td>
</tr>
<tr>
<td>Shiquanhe original</td>
<td>-11.15</td>
<td>11.29</td>
<td>12.21</td>
</tr>
<tr>
<td>Shiquanhe revised</td>
<td>-1.66</td>
<td>3.82</td>
<td>5.18</td>
</tr>
</tbody>
</table>
Performance of revised Noah - at Gaize site

Error metrics for daytime (09:00-16:00 local time)

<table>
<thead>
<tr>
<th></th>
<th>$T_{sfc}$</th>
<th>$H$</th>
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<tbody>
<tr>
<td></td>
<td>BIAS</td>
<td>MD</td>
<td>RMSD</td>
</tr>
<tr>
<td>Gaize</td>
<td>original</td>
<td>-10.18</td>
<td>10.19</td>
</tr>
<tr>
<td></td>
<td>revised</td>
<td>-2.62</td>
<td>3.73</td>
</tr>
</tbody>
</table>
Performance of revised Noah - at Dunhuang site

Error metrics for daytime (09:00-16:00 local time)

<table>
<thead>
<tr>
<th></th>
<th>$T_{sfc}$</th>
<th>$H$</th>
<th>$R_{net}$</th>
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<td></td>
<td>BIAS</td>
<td>MD</td>
<td>RMSD</td>
</tr>
<tr>
<td>Dunhuang</td>
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<tr>
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<td>-4.99</td>
<td>5.15</td>
<td>5.93</td>
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<tr>
<td>revised</td>
<td>-2.44</td>
<td>2.96</td>
<td>3.86</td>
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</table>
Mean Biases at the three sites

- Tg (K)
  - Dunhuang: original -15, revised -12
  - Shiquanhe: original -9, revised -6
  - Gaize: original -3, revised 0

- Rn (W m\(^{-2}\))
  - Dunhuang: original 0, revised 30
  - Shiquanhe: original 90, revised 120

- H (W m\(^{-2}\))
  - Dunhuang: original 0, revised 10
  - Shiquanhe: original 30, revised 40
Performance of revised Noah - at Audubon site

Error metrics for daytime (09:00-16:00 local time)

<table>
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<tr>
<th></th>
<th>$T_{sfc}$</th>
<th>$H$</th>
<th>$R_{net}$</th>
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<td>$RMSD$</td>
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<tr>
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Performance of revised Noah - at Tongyu site

<table>
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<th>Tongyu-G</th>
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<th>H</th>
<th>Rnet</th>
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<td>BIAS</td>
<td>MD</td>
<td>RMSD</td>
</tr>
<tr>
<td>original</td>
<td>-1.48</td>
<td>1.58</td>
<td>1.92</td>
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<tr>
<td>revised</td>
<td>0.31</td>
<td>0.66</td>
<td>0.79</td>
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</tbody>
</table>
Simulated mean diurnal variation of $\ln(z_{oh})$ throughout the simulated period for (a) Dunhuang site, (b) Shiquanhe site, and (c) Gaize site.

The values of $z_{oh}$ simulated by the revised model exhibit evident diurnal variations, which was not represented by the original Noah LSM.

The values of $z_{oh}$ produced by the revised model exhibits the larger amplitude of diurnal variation at two TP sites than at Dunhuang site.
Yang, K., Y.-Y. Chen, and J. Qin, 2009:
Some practical notes on the land surface modeling in the
Tibetan Plateau,

Chen YY, K. Yang, D-G Zhou, J. Qin, X-F Guo:
Improving Noah Land Surface Model in Arid Regions with
an Appropriate Parameterization of the Thermal Roughness
Length.
Journal of Hydrometeorology, in press.
Summary

- Diurnal variations of $z_{0h}$ are common for all bare-soil surfaces and particularly outstanding for Tibet sites, indicating that $z_{0h}$ and $kB^{-1}$ are flow-dependent;

- Surface radiation and energy budget modeling is sensitive to the parameterization of diurnal variations of $z_{0h}$ or $kB^{-1}$;

- Dryland surface modeling is much improved after implementing a parameterization scheme into SiB2 and Noah models.
Outline

♦ Philosophy of process studies

♦ Data analysis for heat transfer resistance over bare soil surface

♦ Heat transfer resistance was under-estimated in models: results from CEOP model inter-comparison

♦ Can models be improved after implement a realistic flux parameterization scheme?

♦ Field work and lab. experiments contribute to new knowledge
Case 1

Glacio-meteorological Investigations on a Glacier in the Southeast Tibetan Plateau

*ITP hydro-meteorological group and glaciological group*
1. Academic motivations

♦ Glacio-meteorology

Energy budget:

\[
Energy = R_{\text{net}} - H - lE - G + Q_{\text{prec}}
\]

Cryospheric mass balance:

\[
Balance = Prec - \text{Runoff} - \text{VaporExchange}
\]
How to calculate glacier melting

1. Glacier melting

\[ \psi = R_{net} - H - lE - G + Q_{prec} \]
\[ M = \frac{\psi}{L_m} \]

2. Degree-day

\[ M = \begin{cases} 
  a \cdot T & \text{if } T > T_t \\
  0 & \text{if } T \leq T_t 
\end{cases} \]
Similarity Theory to calculate \( H \) and \( lE \)

\[
H = \frac{\rho C_p k^2 u(z)(T(z) - T_0)}{(\ln \frac{z}{z_{0m}})(\ln \frac{z}{z_{0t}})} (\phi_m \phi_v)^{-1}
\]

\[
lE = \frac{\rho L_v k^2 u(z)(q(z) - q_0)}{\ln(\frac{z}{z_{0m}})\ln(\frac{z}{z_{0q}})} (\phi_m \phi_v)^{-1}
\]

**Bulk Richardson number** \( R_i_b > 0 \)

\[
(\phi_m \phi_h)^{-1} = (\phi_m \phi_v)^{-1} = (1 - 5Rb)^2
\]

\( R_i_b < 0 \)

\[
(\phi_m \phi_h)^{-1} = (\phi_m \phi_v)^{-1} = (1 - 16Rb)^{0.75}
\]

How to get \( z_{0q}, z_{0h} \)?
2. Field experiment / phenomenology

♦ Basic information
  Palong-Zangbu No. 4 glacier
  southeast Tibetan Plateau
  4800 m ASL
  late May ~ early Sept., 2009

♦ Joint effort
  hydrometeorology
  glaciology
In the ‘field’

*Eddy-covariance system, Radiation, Met. quantity, Ice temp, Mass balance*
Roughness lengths

(a) $z_{0,M} (m)$

(b) $z_{0,H} (m)$

(c) $z_{0,Q} (m)$

Date

0520 0527 0603 0610 0617 0624 0701 0708 0715 0722 0729 0805 0812 0819 0826 0902 0909
Heat flux into the glacier is not important!

A simple two-layer subsurface model

\[ G = \rho C_s K_s \frac{\partial T}{\partial Z} \]
Albedo over the glacier does not have diurnal variations
Validation of glacier melting calculation

2009.6.7-8.25

Ablation (mm w.e.)

-5000 -4000 -3000 -2000 -1000 0

6-8 6-22 7-6 7-20 8-3 8-17

-15%

~ +0.3%

\( Z_0 = 0.0047 \text{m} \)
Case 2

Soil stratification
Sites and climate characteristics

Fig. 1. Map showing the climatic system of China including the East Asian and Indian summer monsoons, the winter monsoon winds associated with the Siberian–Mongolian High, and the Westerly winds generalized as the mean locations of jet stream. The summer monsoon is a steady flow of warm, moist air from the tropical oceans, and the winter monsoon is a flow of cold, dry air out of north-central Asia. Compiled from Gao [1], Chinese Academy of Sciences [2] and Zhang and Lin [3].

Two alpine meadow sites: **Amdo**, **Npam**
Performance of three LSMs - At alpine meadow sites

(a) soil moisture

(b) surface temperature

(c) sensible heat flux

(d) latent heat flux

SM1

Tsfc

H

LE

Amdo

Npam
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<thead>
<tr>
<th>Samples</th>
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<th>K(mm/min)</th>
<th>Psi_s(m)</th>
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## Soil organic matters

### Linzhi

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</table>

### Soil organic matters (％) content

- $\leq 1.5$ very low
- 1.5-2.5 low
- 2.5-3.5 medium
- 3.5-5.0 high
- $>5$ very high
86 soil profiles (0-50cm) have been sampled with foil sampler at 37 flux/SMTMS stations.
Sampling

- 33 turbulence stations (11 TORP stations + 20 China drylands network +…)
- 79 soil profiles
- 288 samples
- Measured at TORP 9 stations: soil texture, soil organic matters, porosity, retention curve, hydraulic conductivity, thermal conductivity, heat capacity
Case 3

Soil moisture net work for validation of satellite-retrieved soil moisture
Central TP site:
passive sensor footprint (40 km x 40 km)
Central TP site:
active sensor footprint (5 km x 5km)
At each site

♦ Four levels of soil moisture and temperature measurements
  – 3cm, 20cm, 60 cm, 100 cm
♦ Calibrate moisture sensors
♦ Soil sampling for soil texture analysis at each site
♦ Provide soil freeze-thaw status
♦ Long-term maintenance
Thanks for your attention!